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Water Quality Office
Advanced Waste Treatment Research Laboratory
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TREATMENT OF PRIMARY EFFLUENT BY LIME CLARIFICATION AND GRANULAR CARBON*

R. V. Villiers, E. L. Berg, C. A. Brunner and A. N. Masse**

INTRODUCTION

The singular purpose for treating municipal wastewater is for water pollution control. Conventionally, treatment is achieved by removing the oxygen consuming organic matter wastewater contains in a treatment process which removes the bulk of the suspended organic matter by sedimentation, and a biological or secondary treatment process which removes the bulk of the soluble organic matter by biological oxidation. These processes, when operated in combination, have proved an economical and effective means for removing organic matter from wastewater. However, there are certain disadvantages associated with them.

First, the processes require considerable operating control and often generate operating problems of a complex nature. Second, the processes are easily upset and require time to regain efficient operation. Third, the processes produce sludge at such a rate that it poses an ultimate sludge disposal problem of considerable magnitude.

The foregoing disadvantages are largely associated with biological or secondary treatment, and they could be eliminated if municipal wastewater was treated by a system that did not rely on biological processes. Figure 1 illustrates a plausible treatment system consisting solely of physical and chemical processes. In this treatment system, chemical clarification with lime replaces conventional primary treatment by sedimentation;

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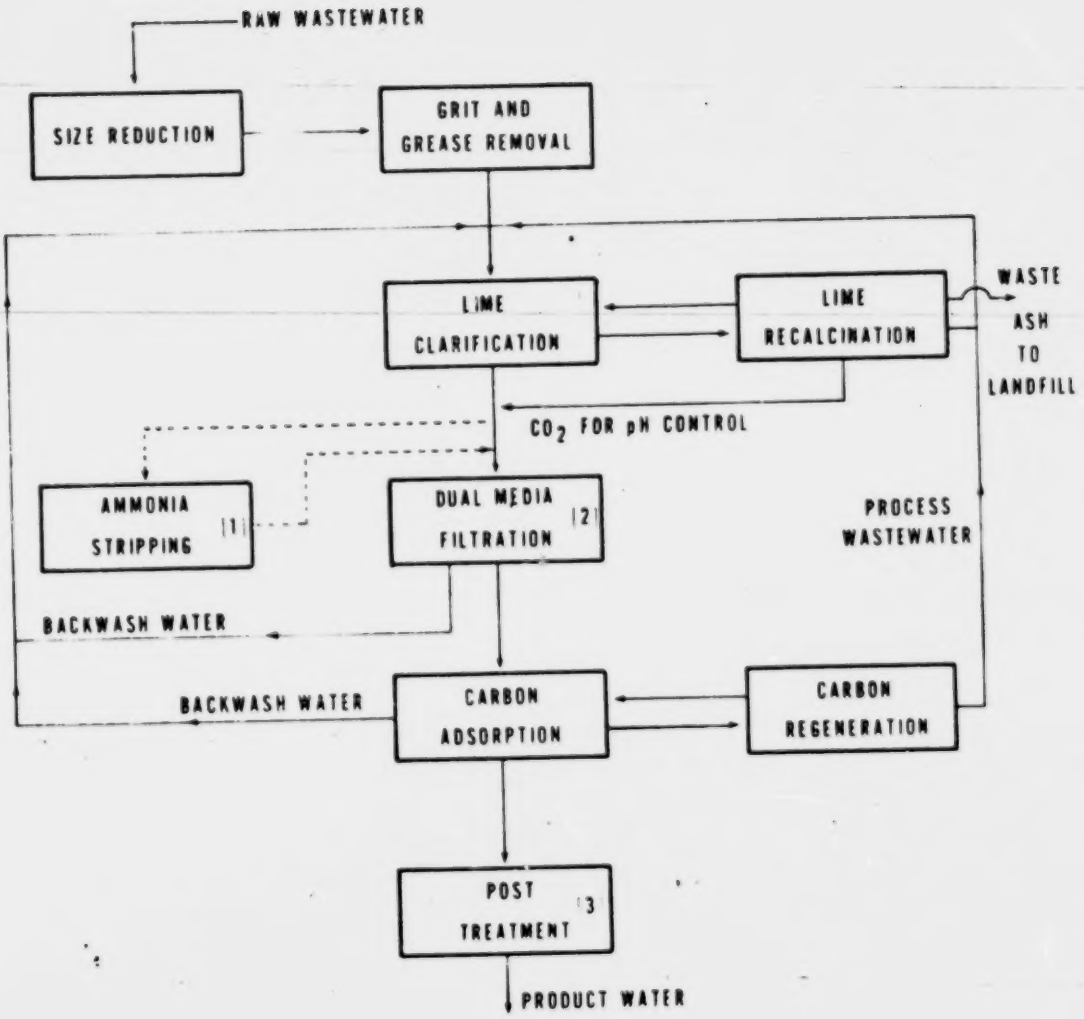

(1) IF NITROGEN REMOVAL IS REQUIRED

(2) COULD BE REPLACED BY FILTRATION IN THE CARBON CONTACTORS

(3) CHLORINATION, OZONATION, ETC.

FIGURE 1

SCHEMATIC DIAGRAM OF PROPOSED WASTEWATER TREATMENT SYSTEM.

activated carbon adsorption replaces conventional secondary treatment by biological oxidation. Recalcination of the spent lime and regeneration of the carbon make the system essentially a closed loop system. The suspended organic matter removed during chemical clarification is incinerated during recalcination of the lime. The soluble organics removed by the activated carbon are combusted during regeneration of the spent carbon. The distinct advantages of such a treatment system are: (1) it would be capable of being turned on and off and of responding rapidly to variation, (2) it would require less complex operating control, (3) it would generate no secondary biological sludges to dispose of ultimately, and (4) it would be predictable and therefore, amenable to instrumentation and automation.

BACKGROUND

The results of applying activated carbon adsorption and lime clarification techniques to wastewater treatment have been widely reported in the literature.[6,2,3,7] Virtually all the work to date, however, has been done on secondary effluent.

Recently a raw wastewater treatment system using lime clarification followed by biological treatment was studied by Schmid and McKinney.[8] Their results showed that lime clarification with recalcination and collateral combustion of the primary solids during recalcination was economically competitive with conventional methods of removing suspended organic solids by sedimentation and their ultimate disposal by incineration. The system had the added benefit of phosphate removal.

In another study, Zuckerman and Molof looked at a treatment system in which raw wastewater was lime clarified at high pH and then carbon treated.[13] These authors contend that the removal of soluble organics by activated

carbon is enhanced by the hydrolytic breakdown at high pH of large molecular weight organic compounds into lower weight organic compounds which are adsorbed more readily by carbon. Final effluent COD values reported were significantly lower than those associated with good conventional treatment.

Weber et al., studied the chemical clarification of primary effluent with ferric chloride followed by carbon adsorption and proposed a system quite similar to that shown in Figure 1.[12] Their results showed that 65 percent of the organic matter present in primary effluent was removed by chemical treatment with ferric chloride. Overall removal of TOC and BOD was reported as being consistently in the range of 95 to 97 percent. Final effluent from the system studied contained approximately 5 mg/l TOC or BOD as compared to 30 mg/l for the same wastewater treated conventionally.

OBJECTIVE

On the basis of work reported to date the proposed treatment system shown in Figure 1 appears to be technically feasible as an alternate to conventional treatment. There remains, however, the need to develop in depth on a large operation scale the answers to two key questions: (1) can activated carbon adsorption compete with biological oxidation as an economical method of removing soiuble organics from lime clarified wastewater; and (2) can a complete physical and chemical wastewater treatment system produce effluent of a quality at least equal to that produced by good conventional treatment?

In an effort to get partial answers to these questions, a lime-clarification and carbon-treatment system was studied on a 0.1 mgd scale at the Lebanon, Ohio Water Renovation Pilot Plant of the Federal Water Quality Administration. The purpose of this paper is to give the results of this study.

METHODS AND PROCEDURES

Figure 2 gives a flow diagram for the experimental system studied. Lime was added to the primary effluent from the Lebanon, Ohio Municipal Treatment Plant in an upflow lime clarifier where suspended organic and inorganic matter and phosphates were removed. The clarifier effluent was filtered through two dual-media filters to capture suspended matter escaping the clarifier. The filtered water was pumped first to a holding tank and then from the holding tank through three carbon contactors for removal of soluble organic matter.

The activated carbon adsorption process consisted of three granular activated carbon contactors, each containing 2400 lbs of 8 x 30 mesh granular activated carbon. This quantity of carbon filled a contactor to a depth of eight feet. The contactors were operated downflow and in series.

Prior to dual-media filtration, the clarifier effluent was adjusted to pH 8 with sulfuric acid to minimize calcium incrustation of the filter media. Following filtration the clarified effluent was further adjusted to pH 7.5 with sulfuric acid prior to carbon treatment.

The clarification process, described in detail by Berg, was operated at a constant flow rate of 75 gpm. Part of the clarifier effluent was stored and used to backwash the dual-media filters; the remainder of the flow went to the holding tank ahead of the carbon contactors. At a flow of 75 gpm, the rise rate of the clarifier was 1 gpm/sq ft, and the surface loading of the dual-media filters was 2 gpm/sq ft each.

Filtered water was pumped from the holding tank through the carbon contactors at a constant rate of 48 gpm providing a 3.8 gpm/sq ft surface loading of the carbon contactors. The empty-bed residence time at this flow

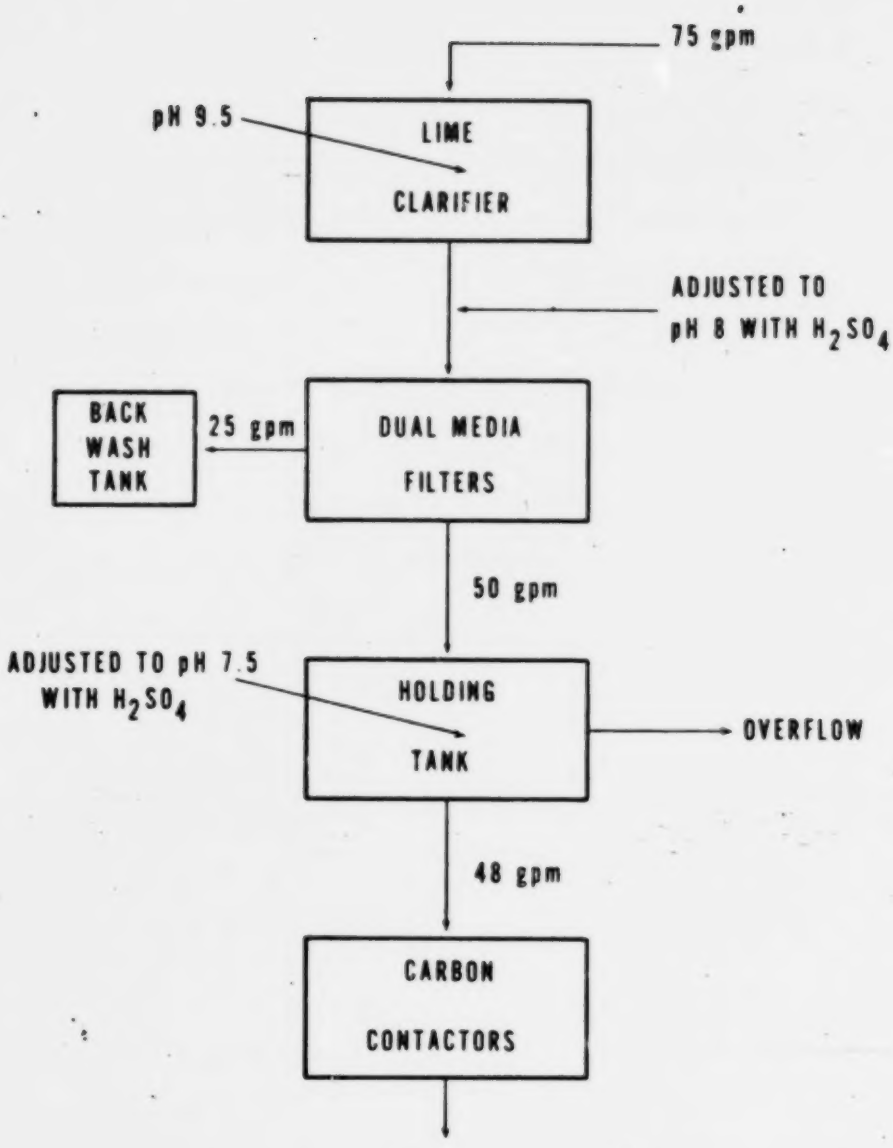

FIGURE 2

FLOWSHEET OF THE EXPERIMENTAL WASTEWATER TREATMENT SYSTEM STUDIED

rate was 15 minutes for each contactor, or a total of 45 minutes for the carbon treatment process as a whole.

The system operated continuously over run lengths of roughly one-month duration. The lime-clarification process never required shutdown during the runs. The carbon contactors were shut down for backwashing when the headloss in the lead contactor was such that a flow of 48 gpm could not be attained. When this occurred, the contactor was shut down, backwashed, and then returned to service. This required about an hour.

Sampling of the system under study was done at first manually by grab sampling every three hours. Midway in the study grab sampling was discontinued and automatic samplers were used to take hourly samples which were then composited over a 24-hour period.

Samples of the feed and product streams of the lime-clarification process were taken for analysis of TOC, BOD, COD, turbidity, suspended solids, and phosphate. The feed and product streams of the carbon process were sampled for TOC, BOD, COD, and turbidity measurements. In addition, the products from carbon contactors one and two were sampled for TOC, COD, and BOD analyses. Feed and product streams of the lime-clarification and carbon processes were sampled over a brief interval for ammonia, nitrite, and nitrate analyses.

All samples were analyzed by Standard Methods except turbidity and TOC.[10] Turbidity results were obtained using a Hach Turbidimeter.* TOC analyses were made with a Beckman Carbonaceous Analyzer.**

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* Hach Chemical Company, Ames, Iowa, Model 1860 Laboratory Turbidimeter.

** Beckman Instruments, Inc., Fullerton, California.

RESULTS AND DISCUSSION

Figure 3 summarizes the performance of the lime-clarification process. The results shown represent data averaged over seven operational periods of the lime-clarification process. TOC, suspended solids, and total phosphate results are based on 15 million gallons of throughput, whereas, orthophosphate and turbidity are based on six million gallons of throughput.

Percentage removals, based on the data given in Figure 3, were calculated for each parameter monitored.. These removals are given in Table 1. The parameters of principal interest are suspended solids, organic matter, and phosphate.

As shown in Table 1, chemical clarification removed 73 percent of the suspended solids that were removed and dual-media filtration removed an additional 18 percent. Ortho and total phosphate were removed only by chemical clarification with 97 percent of the total and 91 percent of the ortho originally present removed. The percentage removal of organic matter was substantially the same regardless of the organic parameter used.

Data in Figure 3 indicate that a considerable fraction of suspended matter originally in the primary effluent escaped capture in the lime clarifier. On the average, dual-media filtration removed 20 mg/l of suspended solids. The TOC results show that these 20 mg/l of suspended solids contained 9 mg/l of organic matter. This suggests that if the suspended solids removal efficiency of the clarification step were improved, the dual-media filtration step could be eliminated with no significant loss in the overall removal performance of the clarification process.

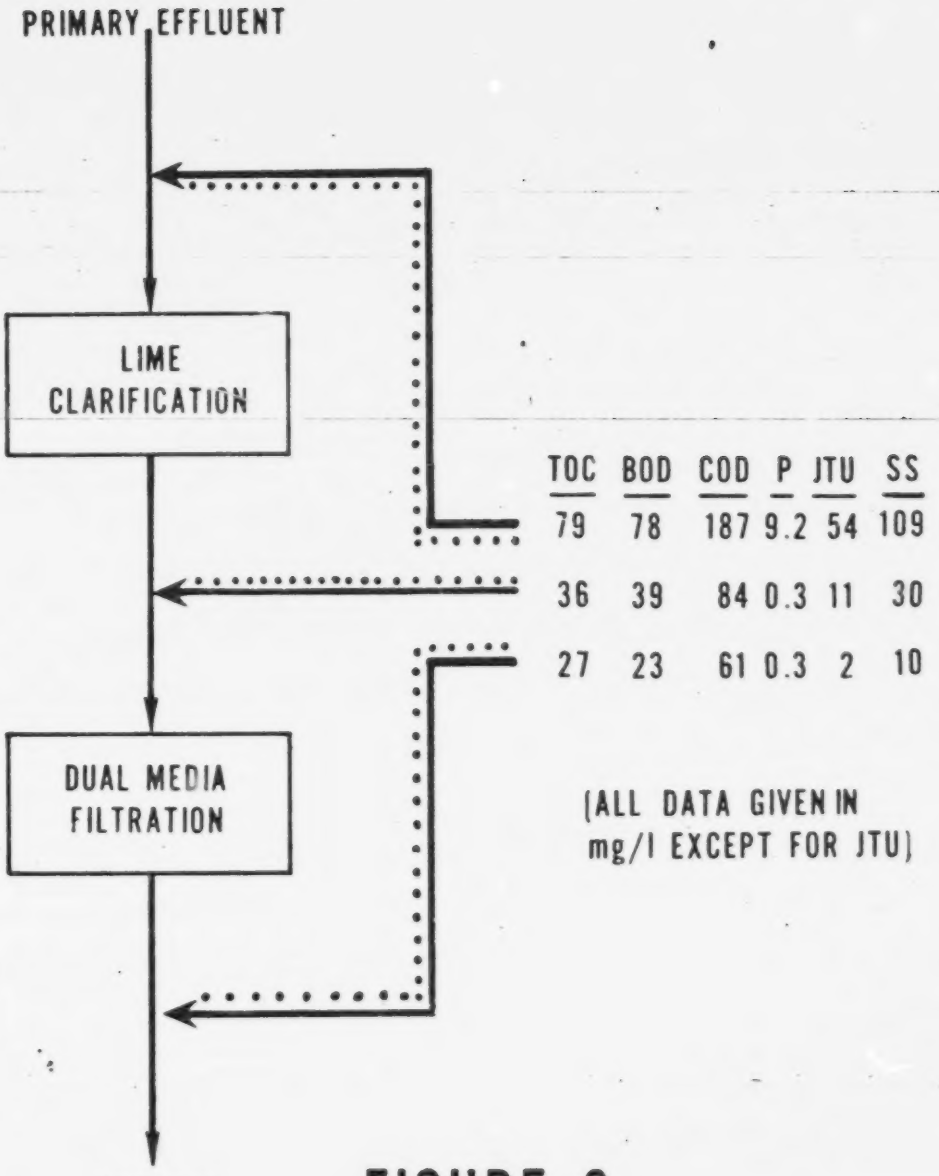

PRIMARY EFFLUENT
LIME CLARIFICATION
DUAL MEDIA FILTRATION
PRODUCT
TOC BOD COD P JTU SS
79 78 187 9.2 54 109
36 39 84 0.3 11 30
27 23 61 0.3 2 10
(ALL DATA GIVEN IN mg/l EXCEPT FOR JTU)

FIGURE 3

SUMMARY OF LIME CLARIFICATION PROCESS PERFORMANCE

TABLE 1

CONTAMINANT REMOVAL BY THE LIME CLARIFICATION PROCESS

	CLARIFICATION	FILTRATION	COMBINED
TOTAL PHOSPHORUS	97%	–	97%
ORTHO PHOSPHORUS	91%	–	91%
ORGANIC MATTER AS			
TOC(1)	54%	11%	65%
BOD(2)	50%	21%	71%
COD(2)	55%	12%	67%
TURBIDITY	80%	17%	97%
SUSPENDED SOLIDS	73%	18%	91%

(1) BASED ON 15 MILLION GALLONS THROUGHPUT

(2)(3) BASED ON 3.7 " " "

Although percentage removals are of interest, the percentage of contaminant not removed is more significant, because this is what ultimately ends up in the receiving stream or is passed on to the next treatment process. In Figure 3, the amount of organic matter remaining in the final product compares favorably with that found in final effluent from many conventional municipal treatment plants. Few conventional treatment plants can produce effluent with suspended solids of 10 mg/l and turbidity of 2. Phosphates are not removed to any great extent by conventional treatment processes.

Carbon Adsorption Process Performance

The results which follow represent data averaged over five operational periods of the carbon contactors during which nine million gallons of lime-clarified and filtered effluent were carbon treated. TOC results are based on nine million gallons of throughput whereas BOD and COD results are based on three million gallons of throughput, and turbidity results are based on five million gallons of throughput.

Contactor one was removed from service after 7.5 million gallons of throughput due to excessive headloss which was not corrected by backwash.

TOC profiles through the carbon contactors for increments of one million gallons of throughput of lime treated, clarified and filtered primary effluent are given in Figure 4. The average TOC of the feed effluent was 23.5 mg/l and the average product was 9.2 mg/l. The range in TOC of the feed effluent was 17.6 to 32.9 mg/l. As can be seen from Figure 4, the effect of this variation in feed effluent TOC on the product TOC was damped by increased removal of TOC by contactor one. Apparently, the lead contactor serves the important function of buffering TOC loadings.

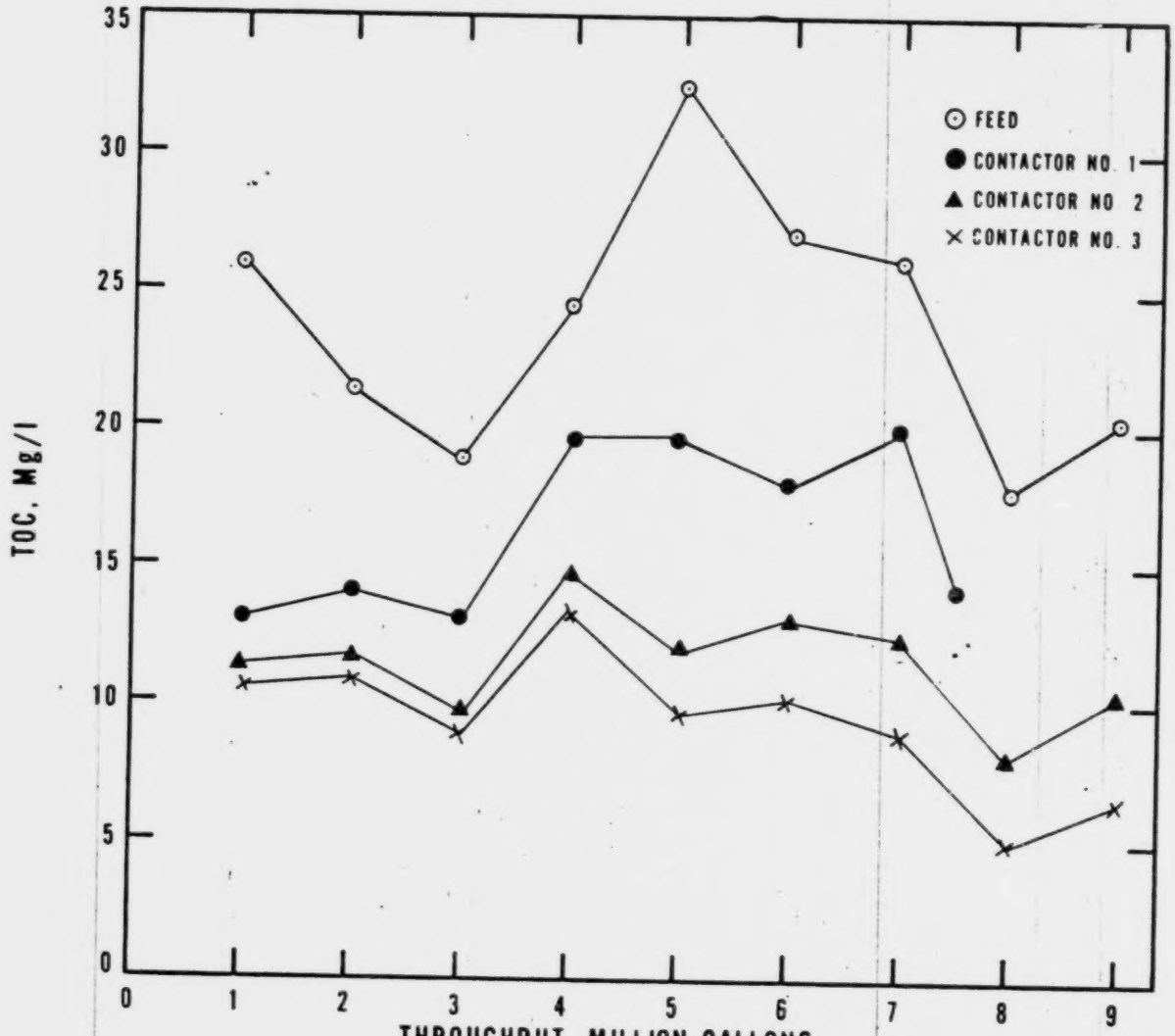


FIGURE 4

TOC PROFILES THROUGH CARBON CONTACTORS

Figure 4 illustrates that product TOC concentration decreased as the total volume of throughput increased. The improvement in product TOC concentration at the nine million gallon increment of throughput as compared to that at the one and two million gallon increments of throughput is not conclusively understood. A plausible explanation, however, is that with operational time, biological populations increased in density within the contactors, and a significant fraction of the organic matter was biologically oxidized. Unfortunately, there is no analytical tool available at present that permits differentiation between organic removal by biological methods and by physical methods.

Figure 4 shows that the removal of contactor one from service, after 7.5 million gallons of throughput, had no apparent effect on product TOC. Since the flow rate remained the same, the removal of contactor residence time changed from 45 minutes to 30 minutes.

Table 2 shows the percentage of organic matter removed by the carbon contactors. Organic removal was about the same regardless of the parameter used as a quantitative measure.

An important parameter is the amount of TOC removed per pound of carbon. Table 3 gives the cumulative contactor loading in pounds of TOC and in pounds of TOC removed per pound of carbon. In gallons of throughput, this loading is roughly 3200 gallons per pound of carbon. Considering that contactor one was only partially exhausted at shutdown, the results indicate a potential treatment of 5,000 gallons of thoughput per pound of carbon, or a usage of 200 pounds of carbon per million gallons of throughput and at this carbon usage the cost to treat one million gallons is estimated at $10.00 if the carbon is regenerated and $52.00 if the carbon is used on a one time basis.

TABLE 2

PERCENTAGE OF ORGANICS REMOVED FROM LIME CLARIFIED PRIMARY BY CARBON TREATMENT

TOC[1]	61
BOD[2]	59
COD[2]	60

(1) BASED ON 9 MILLION GALLONS THROUGHPUT

(2) BASED ON 3 " " "

TABLE 3

TOC LOADING OF CARBON CONTACTORS AFTER NINE MILLION GALLONS THROUGHPUT

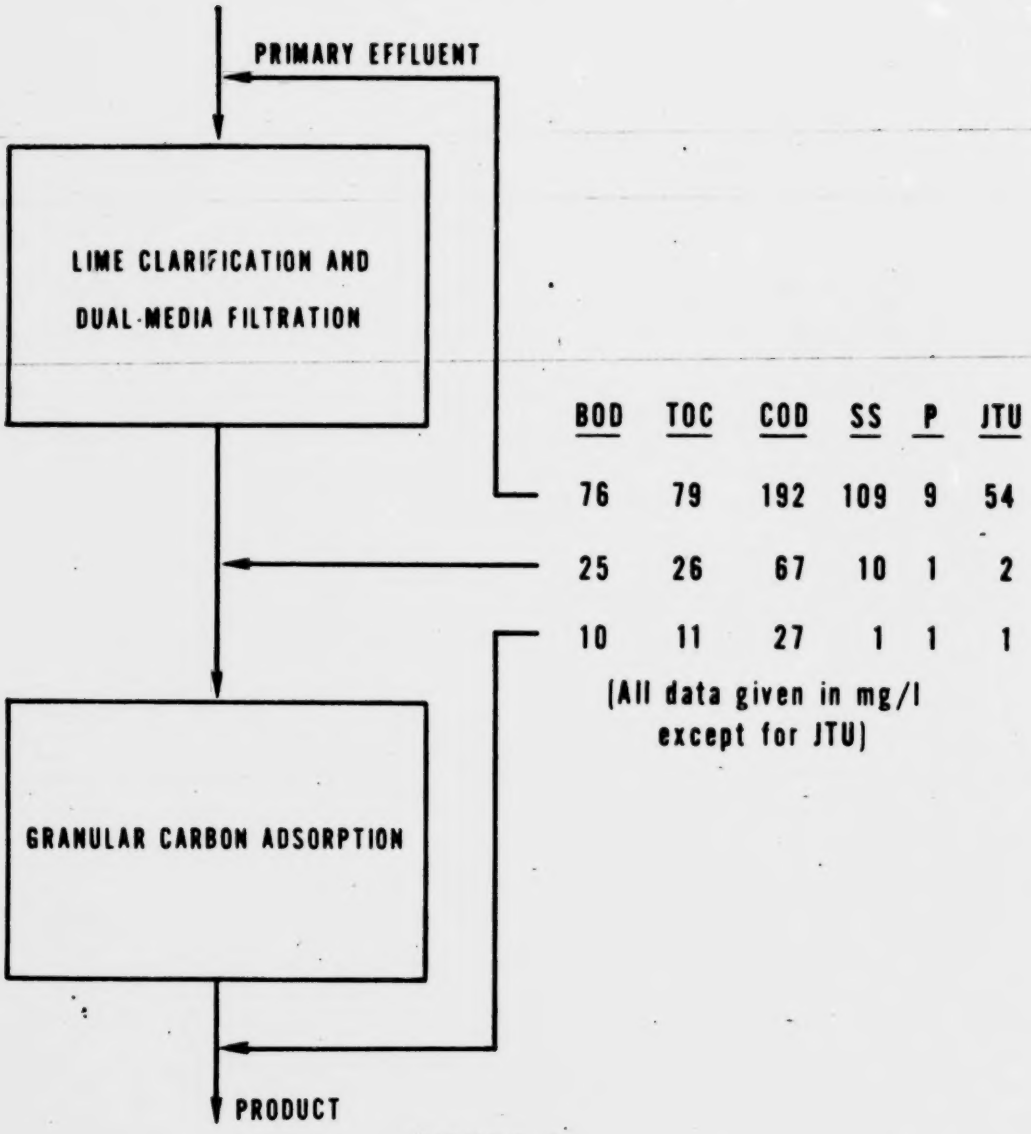
CONTACTOR NUMBER	LBS TOC REMOVED	LBS TOC REMOVED PER LB CARBON
1	530	0.22
2	465	0.19
3	170	0.07

OVERALL SYSTEM PERFORMANCE

Figure 5 gives a summary of the overall performance of the treatment system. Based on organic removal as measured by TOC, 78 percent of the organic matter removed by the system was removed by the lime clarification process, and 22 percent by carbon treatment. Overall removal by the system of TOC matter present in primary effluent averaged 86 percent. If 35 percent removal of TOC by primary treatment is assumed, the total removal of TOC by primary treatment, lime clarification, and carbon treatment would be greater than 90 percent. It is anticipated that raw wastewater could be fed directly to the lime clarifier without affecting product quality.

Removal of turbidity, suspended solids, and phosphate by the system was also very good. Each of these parameters averaged 1 mg/l in the final product. As would be expected, the carbon contactors removed suspended solids, and thus turbidity that escaped the dual-media filters.

Table 4 gives a comparison between wastewater quality attainable by good conventional treatment and that attained in the present study by lime clarification and carbon treatment. The data given for activated sludge treatment were obtained from measurements made on secondary effluent from a small activated sludge unit located at the Lebanon Pilot Plant Facility. This unit operates at a constant flow rate and treats primary effluent from the Lebanon Municipal Treatment Plant by conventional activated sludge methods. The secondary effluent produced by this unit is normally of good quality with an organic content of 20 mg/l or less and a turbidity of 10 or less. Data in Table 4 indicate the quality of effluent produced by lime clarification and carbon adsorption was slightly better than that of the secondary effluent used as the standard, and probably much better in quality than the effluent produced by the majority of treatment plants that use conventional treatment processes.



BOD	TOC	COD	SS	P	JTU
76	79	192	109	9	54
25	26	67	10	1	2
10	11	27	1	1	1

(All data given in mg/l except for JTU)

FIGURE 5

SUMMARY OF SYSTEM PERFORMANCE

TABLE 4

COMPARISON OF CONVENTIONAL TREATMENT AND PHYSICAL AND CHEMICAL TREATMENT

TREATMENT	BOD[1]	TOC[1]	JTU
ACTIVATED SLUDGE	79-13[a]	59-12[b] 72-12	2.4
LIME AND CARBON	76-10	76-10	1.1

(1) BASED ON 1 MG THROUGHPUT

(a) FIRST GROUP OF FIGURES ARE INFLUENT, SECOND GROUP EFFLUENT

(b) RESULTS FROM TWO SEPARATE SAMPLING PERIODS.

GENERAL COMMENTS

In assessing the results presented, two factors must be considered. First, the system under study was operated at steady flow. The effect of diurnal variation in the flow of wastewater on the performance of the system was not determined. There is some evidence, however, that several magnitudes of change in flow rate through a carbon contactor do not materially affect product quality.[10,4] The effect of variation in flow on the performance of the lime clarification process is not known.

Second, the primary effluent used as the feed to the system was highly domestic in nature and was weak-to-moderate in strength. Conceivably, the results would have been altered if a stronger wastewater were treated.

The results should also be considered in light of certain deficiencies in the system studied. A principal deficiency lay in the inability to backwash the carbon contactors efficiently. This most likely resulted in the establishment of a microbial population in the contactors, particularly the first one. Undoubtedly, some of the organic matter removed in the contactors was removed through biological metabolic activity.

A second process deficiency arises from the fact that the contactors operated anaerobically. This presents an ultimate problem of removing the hydrogen sulfide gas from the product. Air stripping would create odor problems. Oxidation to sulfate with chlorine or ozone could be costly. Costs involved, however, could be compared to costs of oxygenating the contactors to prevent them from becoming anaerobic.

ECONOMICS

Estimated capital and operating costs for a 1, 10 and 100 mgd lime-clarification and carbon-treatment system are given in Table 5. Costs for the lime clarification process were based on a single-stage upflow clarifier and include the cost of dual-media filtration and recalcination. Costs for the carbon adsorption process include regeneration. Lime loss upon recalcination was estimated at 20 percent. Carbon regeneration loss was estimated at 5 percent. Cost data is from Smith, Eilers, and McMichael. Design parameters used in the cost estimates were essentially those shown in Table 6.

Table 7 gives the costs for a 10 mgd conventional treatment plant. Total costs shown include the costs of processing and disposing of sludge by thickening, filtering, and incineration. These cost data are from Hager and Reilly, but modified to reflect amortization cost of 6 percent for 25 years and adjusted to January 1970 dollars.[5]

Estimated capital costs indicate that a physical and chemical treatment plant similar to that shown in Figure 1 costs less to build than conventional plants. Consideration, however, must be given to the method of waste sludge processing and handling since considerable capital costs are involved. In those instances where sludge is ultimately disposed of by anaerobic digestion followed by sand-bed drying, and then disposal to landfill, capital costs probably favor conventional treatment plants over physical and chemical ones.

Operating costs for a physical and chemical treatment plant are higher than those for a conventional treatment plant at a plant size of 10 mgd. Again, however, consideration must be given to sludge disposal, since amortization of capital costs of which sludge disposal can be a major portion are reflected in the operating costs.

Table 5

Estimated Capital and Operating Costs for 1, 10, and 100 mgd Lime Clarification and Carbon Adsorption Municipal Wastewater Treatment Plants

	1 MGD	10 MGD	100 MGD
Lime Clarification Process			
Capital Costs, $	400,000	1,600,000	7,160,000
Amortization of capital, ¢ per 1000 gal	8.6	3.4	1.6
Operating and maintenance costs, ¢ per 1000 gal	15.3	6.5	3.5
Total treatment cost ¢ per 1000 gal	23.9	9.9	5.1
Carbon Adsorption Process			
Capital costs, $	400,000	1,700,000	12,190,000
Amortization of capital, ¢ per 1000 gal	8.6	3.6	2.6
Operating and maintenance ¢ per 1000 gal	23.7	7.2	4.6
Total treatment cost ¢ per 1000 gal	32.3	10.8	7.2
Total Treatment System			
Capital costs, $	800,000	3,300,000	19,350,000
Amortization of capital, ¢ per 1000 gal	17.2	7.0	4.2
Operating and maintenance costs, ¢ per 1000 gal	39.0	13.7	8.1
Total treatment cost ¢ per 1000 gal	56.2	20.7	12.3

Table 6

Design Parameters for Municipal Wastewater Treatment Plants
Using Lime Clarification and Carbon Adsorption

Lime Clarification Process	
Clarifier	
Rise rate	1 gpm/ft^2
Range of variation	to 5 gpm/ft^2
Operation	Upflow
Operational pH	9.5
Lime dosage	250 mg/l
Range of variation	150-350 mg/l
Dual Media Filtration	
Surface Loading	2 gpm/ft^2
Range of variation	to 5 gpm/ft^2
Carbon Adsorption Process	
Operation	Downflow
Operational pH	7.5
Surface Loading	7 gpm/ft^2
Range of variation	to 14 gpm/ft^2
Carbon particle size	8 x 30 mesh
Residence time, empty bed	50 minutes

Table 7

Estimated Capital Costs for a 10 MGD Conventional Activated Sludge Treatment Plant With Sludge Disposal by Thickening, Filtration and Incineration*

Capital Costs, $		3,950,000
Operating Costs ¢/1000 gallons		
	Primary treatment	4.0
	Secondary treatment	3.0
	Sludge disposal	4.5
Amortization of capital,** ¢/1000 gallons		8.5
Total Costs, ¢/1000 gallons		20.0

* January 1970 dollars
** 6% over 25 years

In general, pending the accumulation of actual operating and capital costs, about all the estimated cost data can show at this time is that at plant size of 10 mgd or greater capital costs are less, but operating costs are slightly more for a physical and chemical treatment plant than a conventional treatment plant which ultimately disposes of sludge by incineration. Subtle costs, such as those that might be involved in eliminating hydrogen sulfide from carbon contactor effluent, are not reflected in the costs presented. Also, the costs involved, if a conventional treatment plant removes phosphorus, is neglected.

The economics of replacing biological treatment by carbon treatment appear attractive. Based on the performance of carbon contactor one, prior to shut down and estimating that it was only two-thirds exhausted at shut down, a usage of carbon is projected at one pound for each 5,000 gallons of lime-clarified primary treated. At a carbon cost of $0.26 per pound, the carbon cost to treat 1000 gallons is roughly $0.05 on a one-use basis. With regeneration of the carbon and assuming a 5 percent regeneration loss of carbon, the carbon cost to treat 1000 gallons of clarified primary effluent is estimated at less then $0.01.

Conversion of biological treatment to granular carbon treatment in older conventional plants could conceivably be achieved by converting the aeration tanks to gravity flow carbon contactors. This would affect capital and operating cost savings through elimination of pumps. Furthermore, conversion of old construction could be done conservatively at 50 percent the cost of new construction. This would reduce carbon treatment costs by about $0.02 to $0.03/1000 gallons and bring total treatment costs by carbon to around $0.07-0.08/1000 gallons. This compares favorably with new construction costs for biological treatment estimated from Table 7 at $0.08/1000 gallons.

Thus, soluble organic removal, either by biological means or by carbon treatment, is at least economically comparable. Therefore, the possibility of upgrading treatment performance in older treatment plants by converting from biological treatment to carbon treatment should not be overlooked. However, any economic advantage between these modes of organic removal is marginal in favor of carbon treatment at this time.

Possibly physical and chemical treatment could be made more economically attractive at a small plant scale through the cooperative sharing of the capital and operating costs of a calcinator and a carbon regenerator by a number of plants. Also, it might be economically favorable for a large treatment plant to regenerate chemicals and carbon for itself and for a number of small plants. It is quite comprehensible to project the possibility of treating wastewaters generated within a watershed by physical and chemical methods at their sources but to regenerate chemicals and carbon at one central site within the watershed.

SUMMARY AND CONCLUSIONS

The results of the study presented show that treatment of primary effluent by lime clarification and activated carbon produces a product of good quality. Averaged over a nine million gallon throughput, product TOC averaged 11 mg/l with an overall range of 2-23 mg/l. Product turbidity averaged less than 2. Phosphate and suspended solids removal were consistently 90 percent or better. These product characteristics are comparable to those associated with product from well operated conventional treatment plants.

The results presented must be considered in light of certain factors. First, the system was run at steady flow. Second, the feed to the system was a weak-to-moderate strength domestic wastewater. How the system would respond to a number of magnitudes of change in these factors is presently only partially known.

Carbon contactor performance suggests that 5000 gallons of lime clarified primary effluent could be treated per pound of carbon before exhausting the carbon. This projects a carbon make-up cost of $0.05/1000 gallons of wastewater treated without recovery of the carbon, and possibly, less than $0.01/1000 gallons if the carbon is regenerated. These costs indicate that carbon treatment may be competitive economically with biological oxidation as a means of removing soluble organics from municipal wastewater.

Estimated capital and operating costs for different size physical and chemical treatment plants when compared to conventional treatment plants show that a physical and chemical treatment plant will cost less to build but slightly more to operate at plant sizes above 10 mgd. At smaller plant sizes both capital and operating costs are less favorable.

From the study, it is concluded that: (1) wastewater treatment to a quality level comparable to that achieved by good conventional treatment methods is technically feasible using lime clarification and activated carbon treatment, and (2) projected costs based on carbon contactor performance on primary effluent suggest that the removal of soluble organics from raw wastewater by activated carbon treatment should be economically attractive.